Army Research Laboratory

Comparison of a Visual and Head Tactile Display for Soldier Navigation

by Kimberly Myles, Joel T. Kalb, Kim F. Fluitt, and Kathy Kehring

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NOTICES

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14. ABSTRACT

The purpose of the study was to determine the advantages of a head-mounted tactile display (HMTD), compared with a map for Soldier navigation in an urban environment, while concurrently detecting hostile threats. Many technological solutions that provide the Soldier an advantage over the enemy are visually-driven and collectively are in danger of overloading the Soldier's visual capacity, but the tactile modality has been identified as a promising alternative to the visual modality for increasing Soldier performance. Twelve warfighters participated in the study. Each served at least one tour of duty in Iraq or Afghanistan. Participants completed four routes in Middle East (ME) and United States urban virtual environments using a map or an HMTD, while also scanning for and detecting threats. Data were collected for various performance measures, overall workload ratings and a questionnaire. Overall workload significantly decreased by 37.8% when participants used the HMTD, as opposed to the map, to navigate the ME environment. The HMTD was advantageous for decreasing participants' perceived overall workload associated with a complex environment. Thus, for complex environments, off-loading the navigation task to a non-visual modality and reserving visual resources for the task of detecting threats can unburden Soldiers by reducing their overall workload.

15. SUBJECT TERMS

tactile modality, head-mounted tactile display, urban environment, threat detection, overall workload

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1. Introduction

The working environments for nuclear power plant operators, air traffic controllers, and pilots are information intensive. These environments usually involve the indirect control/operation of system processes via displays, forcing the user to assess the system solely through the information collected from multiple visual and auditory displays. The reliance on multiple displays to make informed decisions regarding system status can often lead to information overload on the visual and auditory channels, which can cause an increase in mental and cognitive workload, errors, and missed information and critical system cues. For example, nuclear power plant operators monitor the physical plant status from control rooms that contain huge panels with hard-wired controls and displays (e.g., switches, knobs, handles, alarm tiles, gauges, indicator lights, meters, strip-chart recorders, and trend and bar chart displays) (Kemeny, 1979; Mumaw et al., 2000). In addition to the many displays that operators monitor, they also monitor many alarms. In fact, intermittent and simultaneous activation of many alarms coupled with operator inaction was cited as a major contributor to the events that led to the accident at Three Mile Island (Kemeny, 1979). Air traffic controllers manage many aircraft to control the safety of the airspace and receive data and information from a variety of visual sources (Dasari et al., 2010; Moertl et al., 2002) to make decisions, such as accepting aircraft into their work queue, correcting aircraft conflicts, giving instruction, clearance and advice to pilots, and assigning aircrafts to other work queues and airports (Loft et al., 2007). As increased automation is a likely solution to the projected increase in future air traffic, the air traffic control environment may be inundated with many more visual displays designed to depict the real-time status of airspace (Langan-Fox et al., 2009).

The operators in these dynamic, complex, and multitask environments (1) collect and integrate a plethora of visual information into decisions that are critical for protecting life and the U.S. infrastructure and (2) regularly perform multiple tasks to fulfill the requirement of a single objective (Kemeny, 1979; Loft et al., 2007). Concurrent visual task demands can degrade operator performance because tasks are competing for the same visual processing structures (or visual resources), which are limited and may only be available for the successful completion of one task in which the successful completion of all or other concurrent tasks may suffer (Wickens, 2002). Fortunately, according to multiple resource theory (Wickens, 2002), changing one or more aspects of the task structures in these environments can be beneficial for sustaining or increasing acceptable levels of overall task performance when performing multiple tasks, and reducing the increased workload often associated with multitasking. The perceptual modality through which an operator receives information is one aspect of a task that can be modified to enhance performance for concurrent tasks. For example, two or more tasks that require the use of the visual modality and its limited resources will likely generate overall performance for all tasks that is lower than it would be if one or more of those tasks utilized other modalities

(e.g., auditory and tactile) and those modalities' available resources. This way the visual modality is not overloaded with demands for visual resources that equate to more than the resource capacity of the operator (Wickens, 2008), and operator access to adequate resources for a single or for concurrent tasks should produce an acceptable level of performance. Thus, concurrent tasks requiring resources from different modalities may generate a better outcome for performance than tasks sharing resources within the same modality (Wickens, 2002, 2008).

Similar to the environments discussed above, the Soldier's operational environment presents frequent periods of high workload. The dynamic and complex conditions of the battlefield drive the need for the squad and/or individual Soldier to acquire frequent, real-time, status updates. Unfortunately, many technological solutions that provide the Soldier an immense advantage over the enemy are visually driven, and collectively are in danger of overloading the Soldier's visual capacity (van Erp and Self, 2008), leading to an increase in errors, missed information, and higher workload. This phenomenon may be intensified by the uniqueness of asymmetrical warfare in an urban environment. Such tactical warfare may involve concrete buildings and confining compartments (Groves, 1998), small-arms conventional weapons, improvised explosive devices (IEDs), and a lack of distinction between civilians and enemy combatants (Myles, 2009). Civilians are a big concern, because their presence and assumed autonomy in war can be used by the enemy as a tactic to blend in and disguise themselves as civilians to hide and ambush Soldiers using small-arms weapons and IEDs. This situation can further increase the visual demand placed on the Soldier due to the assiduous need for vigilant threat detection in a callous, hostile environment. The tactile modality has been identified as a promising alternative to the visual modality for increasing Soldier performance by permitting the off-loading of visual information during periods of high visual workload (Redden, 2006), especially when concurrently navigating and scanning for threats (Mitchell et al., 2004).

The ability to identify a hostile threat in one's environment relies on higher-level cognitive resources, such as highly developed mental models of threat and contextual cues associated with threat (Myles, 2009), and is less of a candidate for the intuitiveness of directional cueing offered by current tactile technology. However, conveying navigation information via the tactile modality (as opposed to the visual modality) would allow the Soldier to maintain a visual focus in the environment for the identification of hostile threats (van Erp and Self, 2008) and essentially reduce the navigation task to a task as simple as executing automatic motor responses in response to the intuitive directional cues received on the skin.

Intuitive tactile cues for navigation and alert have been successful in enhancing Soldier performance in visually demanding environments. Although tactile cues can be presented on the torso (Eriksson et al., 2008; Savick et al., 2008), there may be situations where a body-mounted display may be undesirable. For example, in sandy environments, some Soldiers may resist using equipment that is mounted close to the body, which can potentially trap sand against the skin for long periods of time, thus causing skin irritation. Soldiers have also stated that they prefer nonessential equipment and displays that can be extricated from the body

quickly should gunfire erupt and/or the need arise to engage the enemy. The tactile torso belt is mounted under the uniform, and it may not fit the aforementioned criteria for Soldier preference, but a head-mounted tactile display (HMTD) does. Thus, this study seeks to off-load navigation information from the visual to the tactile modality and determine the advantages of Soldiers using an HMTD, compared with a map for navigation, while concurrently detecting hostile threats.

1.1 Hypotheses

The task of navigating in an urban environment while detecting threats is a visually-driven and demanding task. Therefore, we hypothesize that Soldier performance will be superior when using an HMTD to navigate and detect threats within an urban environment, compared with using a map to navigate and detect threats within an urban environment.

Urban environments are defined by concrete buildings and confining compartments, which are favorable for initiating surprise assaults using small-arms weapons, IEDs, and civilians as enemy combatants. We hypothesize that urban environments are not equal and that an urban environment comprised of mostly high-rise buildings (such as a United States urban environment) reduces one's field-of-view of the environment, contributing to a decrease in the number of threats detected. In addition, one's method of movement in such an environment may be more cautious due to the increased possibility of attacks from windows and roofs.

2. Instrumentation and Facilities

2.1 HMTD

The HMTD consists of an adjustable headband designed to hold one tactor (figure 1) at each of the four head locations shown in figure 1. Each tactor is 3 cm (diameter) by 0.79 cm (height), weighs 0.017 kg, and is available commercial-off-the-shelf (COTS). A portable computer (light weight netbook) managed the tactor controller board (figure 2) over a USB interface and supplied audio signals from the headphone audio output to the external signal input of the tactor controller board. The computer generated audio signals with fine gain adjustment and provided routing and gain control to each of the four tactors. The vibratory tactile signal consisted of an amplitude modulated 160 Hz carrier wave at a peak level of 20 dB above tactile threshold. Remote operation was achieved using a wireless router. A second computer was configured using transmission control protocol as a client to transmit one of four directional commands to the netbook, which was configured as a server and used to stimulate the appropriate tactor. The netbook, tactor controller board, and batteries (with a total weight of a little less than 5 lb) were placed in a backpack worn by the Soldier (figure 2).

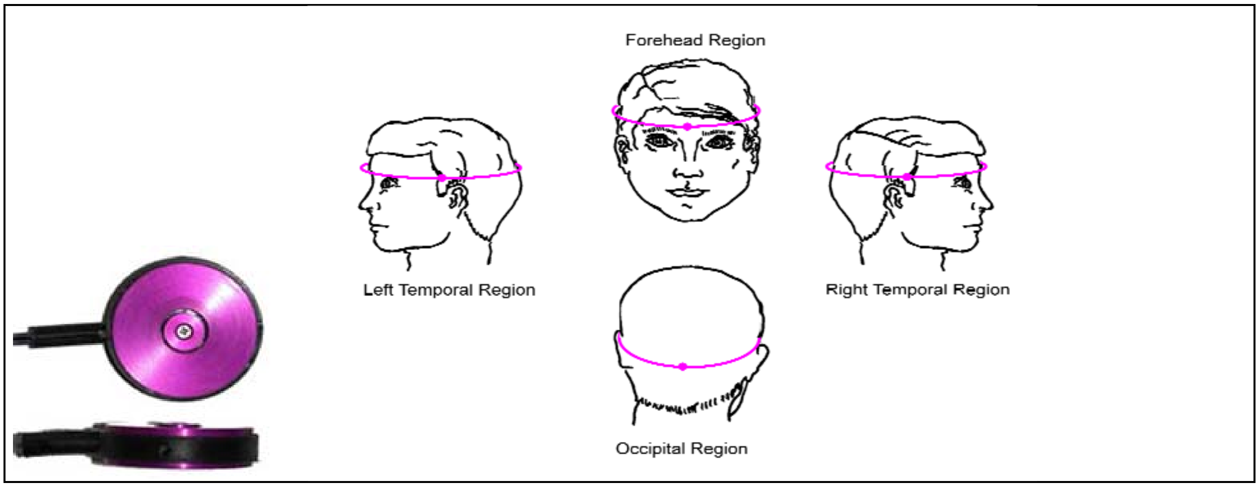

Figure 1. (left) The C-2 tactor designed by Engineering Acoustics, Inc. and (right) the four tactor placements for the HMTD.

Figure 2. (left) Portable HMTD: four tactors, tactor controller board, netbook computer, and user response keypad; (middle) control board and computer designed to be carried in a backpack; and (right) four tactile transducers mounted in an adjustable headband.

2.2 Immersive Environment Simulator and Omni-Directional Treadmill

The study was conducted in the U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate, Tactical Environment Simulation Facility's Immersive Environment Simulator (IES) (located at Aberdeen Proving Ground, MD) using an Omni-Directional Treadmill (ODT). The IES (figure 3), which enables a Soldier to naturally traverse in any direction within a virtual terrain, consists of a four-sided reconfigurable display system (RAVE II, Fakespace Systems, Kitchner, Ontario, Canada) integrated with the ODT (MTS Systems Corp., Eden Prairie, MN and Virtual Space Devices Inc., Ann Arbor, MI) and camera-based motion tracking system (Vicon Motion Systems, Inc., Lake Forest, CA). Positioning the four 12.5 × 10 ft rear-projected screens at 90° to one another completely immerses the user in the virtual environment, providing a full 360° field-of-view.

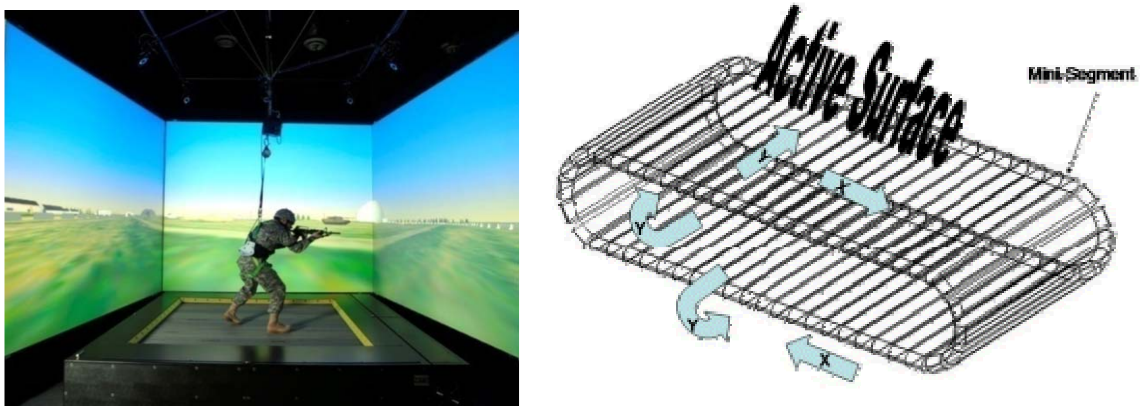

Figure 3. (left) Immersive environment simulator and (right) Omni-directional treadmill belt configuration.

The ODT contains an 8 × 8 ft working surface made up of 80 mini belts that move perpendicularly to a main belt (figure 3), allowing the user to walk, jog, or even crawl in any direction while remaining within the working surface. Clusters of small reflective markers attached to a helmet and a rigid plate on the back of a neoprene waist band worn by the user are tracked in real-time by overhead video cameras. The position of the helmet is used to determine the height of the user's eye-point and accordingly adjusted the perspective of the display, while the speed and heading of the rigid plate are used to determine how the belts of the ODT should move to return the user to the center of the workspace. The speed of the ODT is not set to a constant as in conventional treadmills but is dynamically controlled by the actions of the user. The speed of the ODT is limited to a maximum of 6 mph.

Virtual terrain for this study consisted of two urban environments: a Middle East (ME) urban environment comparable to terrain in Iraq and a United States (U.S.) urban environment comparable to the downtown area of any metropolitan city in the United States (figure 4). The ME urban route was 974.25 m in length and contained 21 correct direction choices and 184 direction options. The U.S. urban route was 993.75 m in length and contained 14 correct direction choices and 84 direction options.

Figure 4. (left) U.S. urban environment and (right) ME urban environment.

2.3 Equipment Load

Participants wore the following equipment (table 1), which is typical for an infantry Soldier conducting a patrol mission in an urban environment.

Table 1. Typical Soldier equipment load for patrol missions in urban environments.

Equipment Load	Weight (lb)
Body Armor	16–24
• Improved outer tactical vest (IOTV).	—
• Weight determined by vest size (S, M, L, XL).	—
Advanced Combat Helmet (ACH), Large	3.25
Dummy M4 carbine with one magazine	7.5
Magazines (6)	3.9
Backpack	3.0
Knee/elbow pads	1.15
Gloves	0.40

Notes: Live ammunition was not carried in any of the magazines, but magazine weight was adjusted to resemble the weight of a magazine fully loaded with live ammunition.
The HMTD added an additional 5 lb of weight to the equipment load for the tactile display condition. The additional 5 lb were also maintained across the map condition.
Total load was 40–48 lb.

3. Method

3.1 Participants

Twelve active-duty, retired, or National Guard warfighters (11 males and 1 female), who served at least one tour in Iraq or Afghanistan were recruited for this study. All were paid $30/hr for their participation except active-duty warfighters. The age range of participants was 18–48 years (M = 34.5, SD = 6.1).

3.2 Experimental Design

A 2 × 2 within-subjects design was used to determine the advantages of using a HMTD compared with a visual display for navigating in an urban environment while simultaneously detecting threats. The presentation order of Display (map, HMTD) and Environment (ME urban terrain, U.S. urban terrain) was counterbalanced. Dependent measures were navigation time, average navigation speed, number of navigation errors, number of threats detected, and overall workload ratings.

Participants navigated each environment twice, once with each display. Each participant's second route in an environment was reversed in that the starting point for the second route was the ending point for the first route. However, for each of the four routes the people, events, and

threats were different but equivalent in terms of complexity. This helped to prevent participants from memorizing the routes and reduce practice effects for each environment over the course of the experiment.

3.3 Tasks, Workload Assessment, and Questionnaire

3.3.1 Navigation

Navigation using the HMTD required participants to execute directional, point-to-point navigation instructions from a 4-tactor array on the head (figure 1) which indicated a left turn via vibration from the left temporal region tactor, a right turn via vibration from the right temporal region tactor, go straight ahead via vibration from the forehead region tactor, and go backward via vibration from the occipital region tactor. The experimenter tracked each participant's real-time position in the IES via an Avatar on an external monitor and manually sent all tactile signals. Additional tactile signals were required to guide the participants back on route if they went off route only after 30 s of the participant being off route. Participants navigated two of the routes using the HMTD.

Navigation using a map required participants to execute directional, point-to-point navigation of the planned routes via paper maps (appendices A and B). How often participants checked the maps for directional cues was left to the discretion of each individual participant. Pop-up windows were initiated by the experimenter, and provided on the IES display screens as required with text messages containing corrective directions to guide the participants back on route if they made a wrong turn. Text messages were initiated after 30 s of the participant being off route. Participants navigated two of the routes using a paper map.

3.3.2 Detection of Hostile Threats

Simultaneously while navigating each route, participants searched for hostile threats and verbally reported to the experimenter when they encountered a threat. The verbal report contained a very brief description of the threat. Threats consisted of individual persons, groups of persons, IEDs, grenades, etc. These are examples and are not a comprehensive list of all possible types of threats. All routes contained six threats and were equally complex in types of threats. The HMTD was not used to convey information regarding threats.

3.3.3 Workload Assessment and Questionnaire

Participants provided overall workload ratings after completing each route. The overall workload scale, a unidimensional absolute estimate of workload (Vidulich and Tsang, 1987), was used for this study (appendix C). Participants were instructed to place a mark on the bipolar scale (0 "low"−100 "high") to indicate their level of overall workload. Following the methodology of Vidulich and Tsang (1987), participants were not privy to the numerical scores, which were later assigned by the experimenter. Verbal instructions were as follows: "Rate the level of workload required to complete the tasks for the route you just completed." In addition, a questionnaire

containing eight questions was used to assess participants' display preference (appendix D). The questionnaire also included questions regarding general phenomenon related to environment, display use and operational setting.

3.4 Procedure

Participants were given the consent form to read and sign and all participant questions were answered by the experimenter. Next, a Titmus i500 vision tester was used to screen participants for 20/20 visual acuity or better in each eye (corrected or uncorrected) and normal stereoscopic and color vision. Participants who passed the screening were then fitted with the ODT safety harness, helmet and belt and the experimenter familiarized them with the operation of the ODT and all of the safety and emergency stopping procedures available to them and the operator. Participants then practiced walking on the ODT until they felt comfortable and appeared to have no hesitation or issues with their balance. Once a level of stability was reached walking on the ODT, participants navigated an urban training route similar to, but shorter than, one of the study routes using a map. Practice sessions lasted for approximately 15–18 min. Next, participants donned the Soldier equipment load typical for patrol missions in urban environments.

Participants then began the study and navigated each environment (ME and U.S.) twice, once with each display (map and HMTD), which equated to each participant completing a total of four navigation routes. Participants donned the headband with four tactors then placed the ACH over the headband when using the HMTD.

After completing each route, participants provided one rating of overall workload. Participants were given a 5 minute break before continuing to the next route. Participants also completed an 8 item questionnaire after all routes were completed. Total time to complete the study was 3.5 h.

4. Results

Five within-subject ANOVAs were conducted for each of the dependent variables (navigation time, average navigation speed, overall workload, number of navigation errors and number of threats detected) to determine if performance measures were affected by environment and display. Significance for all statistical tests was determined at an alpha level of 0.05 (table 2).

The main effect of Environment was significant for navigation time ($p < 0.001$) and average navigation speed ($p < 0.05$). It took participants a significantly longer time to navigate the ME urban environment at significantly slower speeds than in the U.S. urban environment (table 3).

The main effects of Environment and Display were significant for overall workload, ($p < 0.01$) and ($p < 0.05$), respectively. A significant Environment × Display interaction effect ($p <0 .05$) revealed a 37.8% decrease in overall workload when participants used the HMTD as opposed to

the map to navigate the ME urban environment (figure 5). The number of navigation errors and threats detected were not significantly different for main or interaction effects.

Table 2. ANOVA results for performance measures.

Performance Measures	df	MS	F	p
Navigation time (s)				
Environment	1	470250.02	34.13	<0.001
Display	1	83416.69	3.29	0.10
Environment x display	1	30250.52	1.14	0.31
Average navigation speed (mph)				
Environment[a]	1	0.35	8.99	<0.05
Display[a]	1	0.09	0.97	0.35
Environment x display[a]	1	0.01	0.03	0.86
Overall workload				
Environment	1	1078.26	14.52	<0.01
Display	1	2813.67	7.40	<0.05
Environment x display	1	312.63	9.96	<0.05
No. of navigation errors				
Environment	1	10.08	3.59	0.09
Display	1	4.08	2.82	0.12
Environment x display	1	1.33	0.41	0.53
No. of threats detected				
Environment	1	0.08	0.19	0.67
Display	1	1.33	0.83	0.38
Environment x display	1	2.08	1.92	0.19

[a]df (error) = 9 due to a missing data log for the ODT and a data log file being overwritten for two different participants.

Table 3. Means and (standard deviations) for the performance measures.

Performance Measures	Environment		Display	
	ME Urban Terrain	U.S. Urban Terrain	Map	HMTD
Navigation time (s)	995.9 (199.19)	797.9 (153.83)	938.6 (210.96)	855.2 (156.88)
Average navigation speed (mph)	2.21 (0.39)	2.39 (0.52)	2.25 (0.51)	2.35 (0.44)
Overall workload	43.8 (16.85)	34.3 (17.75)	46.7 (17.20)	31.4 (21.38)
No. of navigation errors	1.54 (1.49)	0.63 (0.90)	1.38 (1.38)	0.79 (0.69)
No. of threats detected	3.46 (1.83)	3.38 (1.49)	3.25 (1.76)	3.58 (1.73)

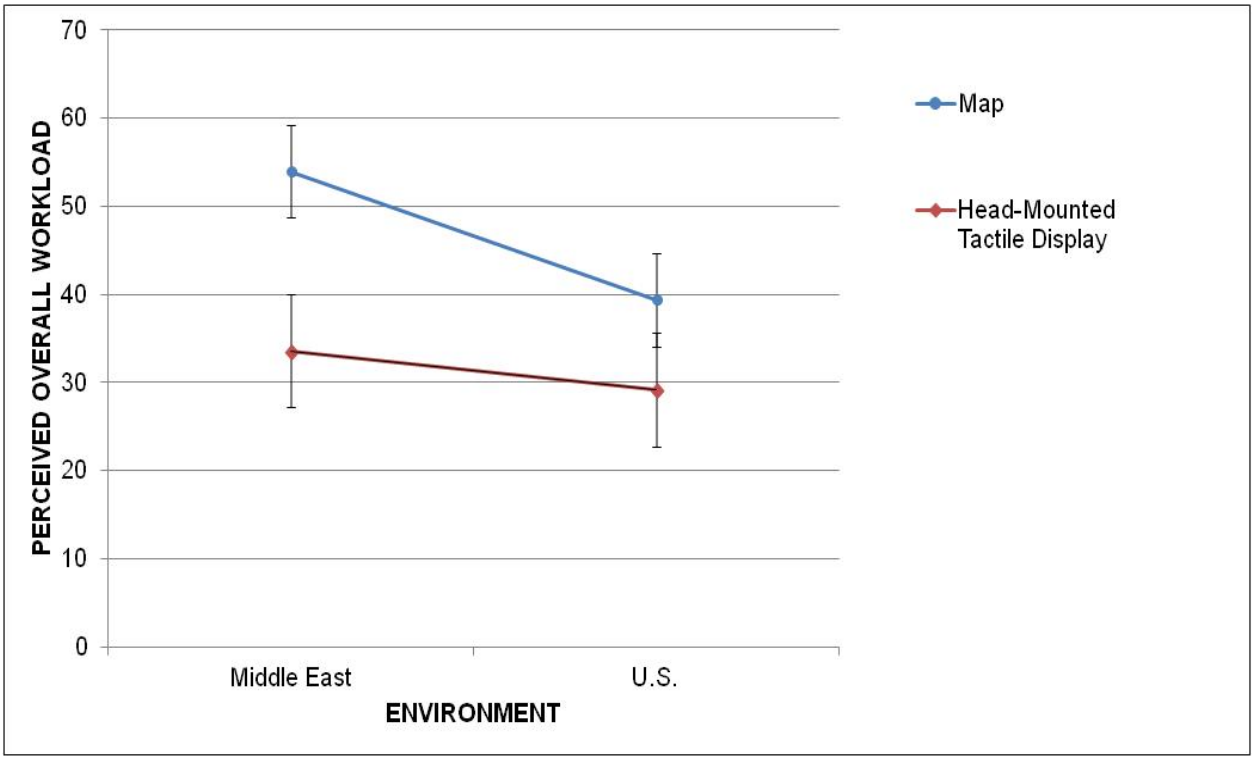

Figure 5. Mean overall workload by display and environment. Error bars represent SE.

5. Discussion

Navigation time, overall workload, and the number of navigation errors were greater for the ME urban environment than for the U.S. urban environment (table 3). Average navigation speed was slower for the ME urban environment than in the U.S. urban environment (table 3). The results show that participant performance decreased in the ME environment. Of 12 participants, 50% found the ME and U.S. environments to be equally difficult whereas 33% found the ME to be the most difficult and 17% found the U.S. to be the most difficult. Navigation time, overall workload, and the number of navigation errors were greater for the map than for the HMTD (table 3). Participant responses support this, as 91% stated that the HMTD was more advantageous for navigation. Average navigation speed was slower when participants used the map to navigate than when using the HMTD (table 3), which may be a consequence of 58% of the participants stating that the frequency at which they directed their attention away from the surrounding terrain was every 30 s (map) as opposed to every minute or every 3−5 min (HMTD). These results may generally support a slight advantage for warfighter performance when using an HMTD to navigate and detect threats within an urban environment compared with using a map.

Navigation time was not significantly affected by display but was significantly affected by the environment. Participants required approximately 3.3 min longer to traverse the ME urban environment which may indicate that the ME environment was more difficult to navigate. Participants also maintained slower speeds when moving through the ME environment. The ME environment contained more buildings than the U.S. environment and by default more potentially incorrect navigational direction options. The ME terrain was comprised of 124.4 × 21.7 m blocks of buildings separated by roads. Each block contained 22 buildings arranged in two rows of 11 buildings (appendix A), which created 20 pathways formed by pathways between each of the 22 buildings and one pathway formed by the separation of the two rows of buildings. The blocks in the U.S. terrain were about 128 × 33−58 m and contained only 1−3 large buildings per block (appendix B). As one participant stated, “The ME environment was more challenging. There were more things going on, more corners to look around and asymmetrical objects to navigate through.” Although the number of navigation errors were not significantly different across environments, the number of errors observed in the ME environment were greater, which also may have had an impact on navigation time. The degraded performance observed for the ME environment is likely attributed to the inherent features of the environment. Thus, this finding confounds affirmative support for a high-rise building hypothesis and its affect on performance. Instead, the main factor affecting performance is likely the complexity of the environments based on the number of navigation options available because there were more buildings and more decision paths in the ME environment.

Navigation times were relatively the same whether participants used the map or HMTD to navigate as we did not block on the warfighter sample for ability in map reading, spatial, or multitasking skills. Twenty-five percent of the sample obtained consistently higher navigation times when using the map in both environments, so it is possible that those who possess good map reading skills and are good at multitasking, may do equally well in completing the task with the map and the HMTD. However, in general, the HMTD may be beneficial for maintaining navigation stride as it reduces the distractions caused by a map, and allows the warfighter to simultaneously follow a route while receiving directional information without stopping or slowing down to check a display for directional information.

Results showed that participants may have significantly expended more physical and mental resources to complete the task of navigating while detecting threats for the ME environment (table 2), which is supported by the higher ratings observed for perceived overall workload for the ME environment (table 3), although multidimensional workload measures are required to substantiate. Specifically, perceived overall workload significantly increased when using the map in the ME environment, compared with the HMTD (figure 5). In other words, navigating with a map while detecting threats and carrying 40–48 lb of weight appeared to be more cumbersome in the ME environment. The distribution of visual resources to read a map to navigate, while maintaining an acceptable level of situation awareness to detect threatening people/things and emerging events capable of causing harm, injury, and/or death, in a complex environment, may

have produced a significant increase in workload ratings. If true, off-loading the navigation information to the tactile modality and its available resources using the HMTD, is assumed to have eased participants' perceived overall workload by 37.8% in the ME environment. Seventy-five percent of the participants stated that the map interfered with their ability to detect threats, with one participant emphasizing that the map required him to direct his attention away from scanning for threats while the tactile display allowed him to execute directions without breaking his focus. A few other comments from participants include the following:

- "The tactile display provided a greater advantage during navigation while detecting threats. The tactile signal allows the Soldier to focus on the mission and limits the distraction. Enhances mission performance and situation awareness."
- "The tactile display relieved the burden of assessing if I was on the right path. The map made me prone to error and distracted me from my priorities while walking."
- "With the tactile display I did not have to look away from an area. I could use the time to scan."
- "The tactile display helped me to navigate well; allowing me to detect threats. The map also made it easier to navigate but took away from threat detection capabilities."
- "The tactile display was the better of the two displays. It allowed me to be hands free, didn't take my attention away from my surroundings. It also allowed for non-verbal communication which will lead to a higher stealth capability."

Participants detected the same number of threats for the ME and U.S. environments and for the map and HMTD. When asked what environment was the most advantageous for detecting threats 33% said neither, 25% said ME, and 42% said the U.S. Again, this is most likely attributed to the diminished complexity of the U.S. environment. Half of the participants obtained threat detection rates above 50% accuracy (M = 81%, range = 67%–92%) and the other participants obtained threat detection rates below 50% accuracy (M = 33%, range = 21%–46%). Consequently, the number of threats detected may have more to do with participant threat detection ability than the identification of the actual threats themselves. It has been stated that most people have below average threat detection abilities (Ekman, 1996), even for those who work in organizations that are considered skilled, threat detection professions (Myles, 2010). This was moderately evident in our sample. We screened our sample for a homogeneous skill set by including warfighters with experience in Afghanistan or Iraq. We had hoped to acquire a sample skillful in navigating and detecting threatening people, things and events in urban environments. Sample definition by military occupational specialty or specific duty on tour may have been a more appropriate approach. It is also possible that threat detection accuracy was affected by the fidelity of the simulated threats where participants may not have identified a potential threat because they did not recognize the simulated depiction of objects.

6. Conclusions

The purpose of this study was to determine the advantages of using an HMTD compared with a visual display (i.e., map) for Soldier navigation in an unfamiliar, urban environment while concurrently detecting hostile threats. The HMTD was found to be more advantageous than a map, in reducing participants' perceived overall workload associated with a difficult-to-navigate environment with a complex layout. The ME urban environment used in this study emerged as complex, increasing navigation time, errors, and overall workload and decreasing navigation speed compared with the U.S. urban environment. Perceived overall workload ratings significantly decreased by 37.8% when participants used the HMTD, as opposed to the map, to navigate the ME environment while concurrently detecting threats.

We hypothesized that participant performance would be affected by the presence of high-rise buildings, in that the participants' approach to operating in such an environment would be more cautious due to the increased probability of threats from roof tops and windows. Instead, the complex layout of the ME environment emerged as the contributing factor to a general decrease in navigation performance, and a significant increase in participants perceived overall workload. Specifically, the number of buildings/block created more direction options than in the U.S. environment and may have contributed to some participants' perception of a challenging operational environment; one in which many corners were required to be negotiated with meticulous caution to avoid civilian attacks and which asymmetrical pathways were accessible pathways. Thus, for environments with complex layouts, off-loading the navigation task to a non-visual modality and reserving visual resources for the task of detecting threats can unburden Soldiers by reducing their overall workload while maintaining, or possibly increasing, those performance measures associated with navigation. But as one participant stressed, only if Soldiers "trust that someone else [is] going to steer [them] in the right direction".

7. References

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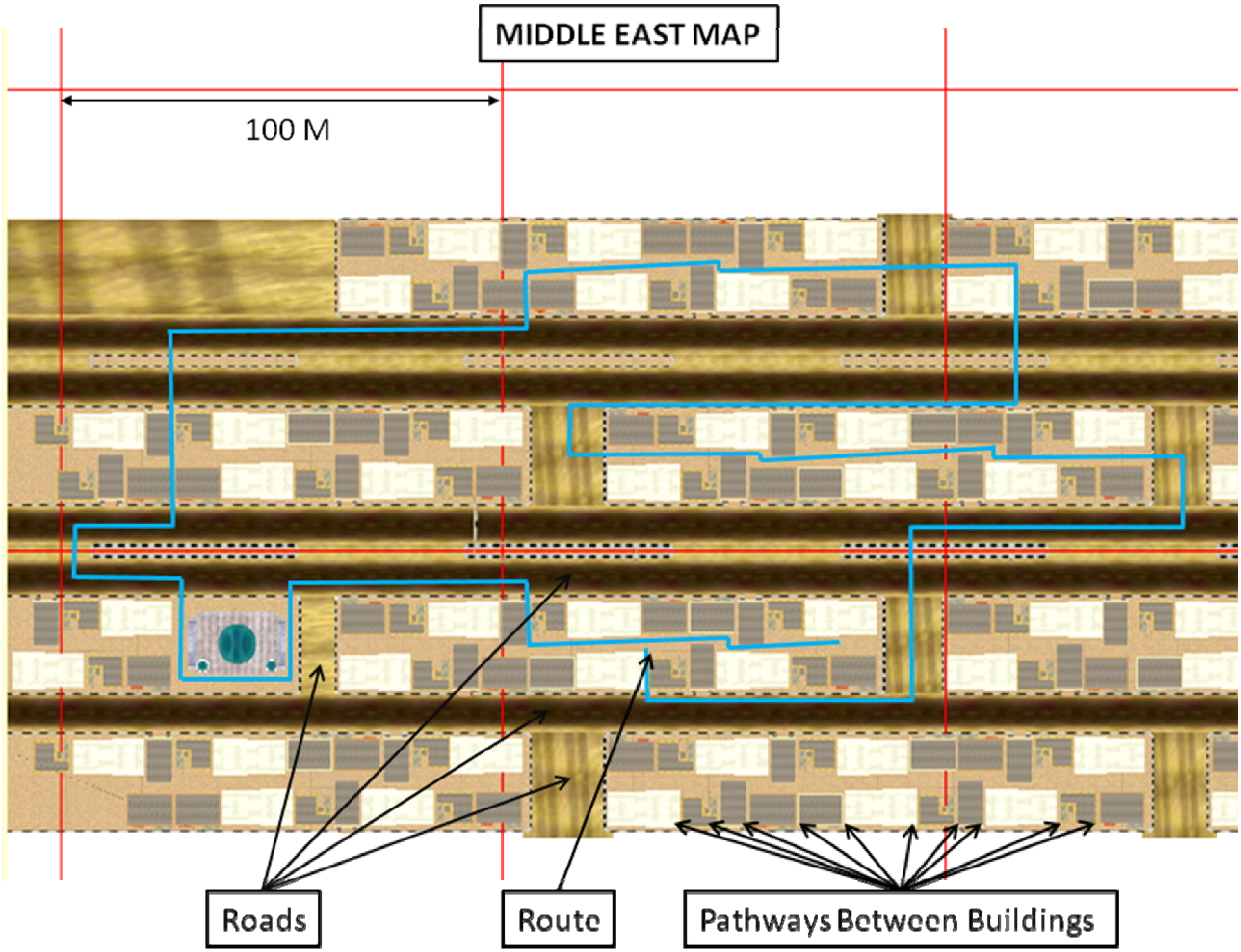
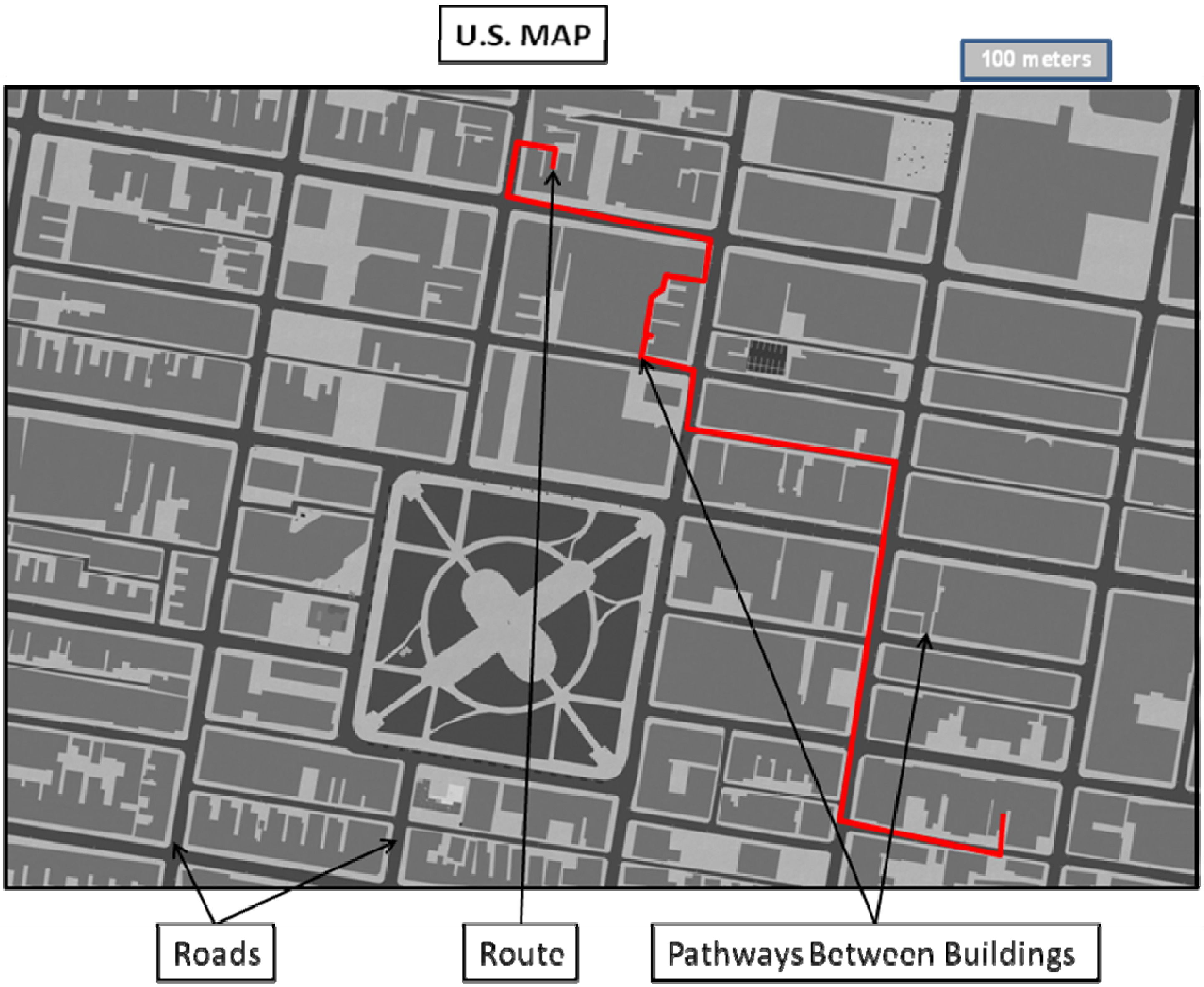
Appendix A. Middle East Terrain Map and Layout

This appendix appears in its original form, without editorial change.


MIDDLE EAST MAP
100 M
Roads
Route
Pathways Between Buildings

Appendix B. United States Terrain Map and Layout

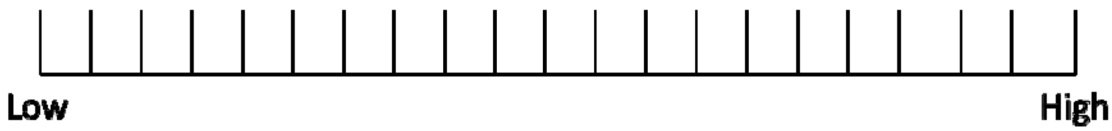
This appendix appears in its original form, without editorial change.


U.S. MAP
100 meters
Roads
Route
Pathways Between Buildings

Appendix C. Overall Workload Scale

This appendix appears in its original form, without editorial change.

Overall Workload



Appendix D. Questionnaire

This appendix appears in its original form, without editorial change.

1. Did the map require you to direct your attention away from the surrounding terrain? If so, please indicate how often by placing a check next to the appropriate time estimate.

Yes ______ No ______

Once every 30 sec _________
Once every min _________
Once every 3 min _________
Once every 5 min _________
Once every 8 min _________

2. Did the head-mounted tactile display require you to direct your attention away from the surrounding terrain? If so, please indicate how often by placing a check next to the appropriate time estimate.

Yes ______ No ______

Once every 30 sec _________
Once every min _________
Once every 3 min _________
Once every 5 min _________
Once every 8 min _________

3. Did you find that the visual display, tactile display or both displays interfered with your ability to detect hostile threats in the low-rise environment? In the high-rise environment? If so, please explain.

4. Did you find that the visual display, tactile display or both displays enhanced your ability to navigate in the low-rise environment? In the high-rise environment? If so, please explain.

5. Which display had more advantages in helping you to successfully navigate while detecting threats? Please describe and explain the advantages that you noticed.

6. Which display would you prefer for operational use in an urban environment? Why?

7. Did you find that the low-rise or high-rise environment was more difficult to navigate? If so, please explain.

8. Did you find that the low-rise or high-rise environment provided more of an advantage in detecting threats? If so, please explain.

Additional Comments: ____
____
____

List of Symbols, Abbreviations, and Acronyms

ACH	Advanced Combat Helmet
ARL	U.S. Army Research Laboratory
COTS	commercial-off-the-shelf
HMTD	head-mounted tactile display
IED	improvised explosive device
IES	Immersive Environment Simulator
IOTV	Improved outer tactical vest
ME	Middle East
ODT	Omni-Directional Treadmill
U.S.	United States

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